Application Note

Driving Latching Relays with eFuse in Smart Electricity Meter

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Abstract

The ability to monitor live power consumption and remotely connect or disconnect electric service to customers is a foundational feature for a smart electricity meter. Utility operators remotely control latching relays in smart electricity meters to connect or disconnect electric service for reasons, such as emergency or immediate safety concerns, failure to pay bills, or even a service restart recharge of pre-paid accounts in case of pre-paid smart electricity meter. This application note discusses how an eFuse can be used to facilitate available power from the source during relay operation, which leads to a reduction in the hold-up energy needs, and hence lowers the hold-up capacitor size. This document also provides design and measurement results showing the performance benefits of using eFuse .

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1 Introduction

Technical advancements in smart-emeters have enabled advanced metering, demand tariff, and customer display for management. These advancements must be managed with less power consumption from the utility grid while maintaining the same form factor for the smart e-meter.

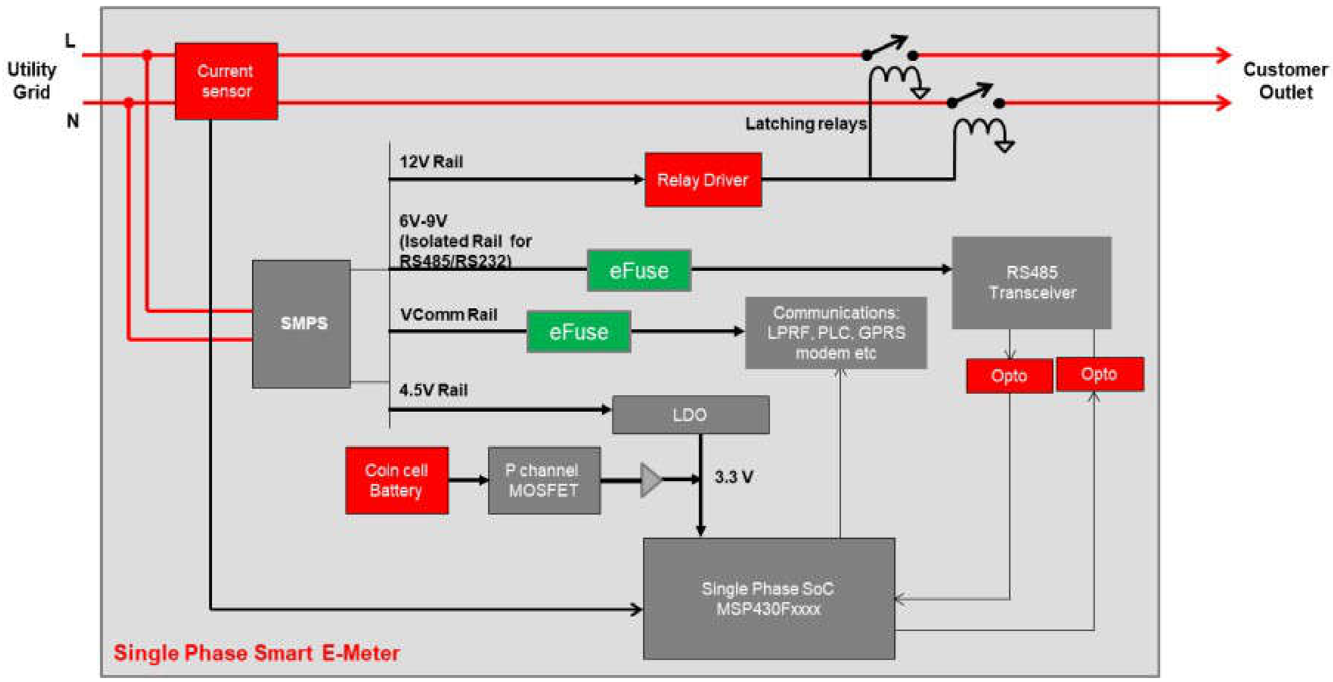

Figure 1-1. Single Phase Smart E-Meter Block Diagram

A smart e-meter runs multiple internal modules, including the metrology core, central processor, communication modem,and latching relays as shown in Figure 1-1. While standard operations require minimal continuous power, the e-meter demands large power during wireless data transmission and the mechanical latching of the relay. Before quantifying the smart e-meter power requirements, it is useful to understand the operation of latching relay. The latching relay operation and its associated power requirements are described below .

Latching relays are used by the electrical utility operators to remotely connect/disconnect electric service for reasons, including emergency or immediate safety concerns, failure to pay bills, or even a service restart recharge of pre-paid accounts (prepaid e-meter). Relays requires a pulse of current to connect and disconnect the electrical services. During this, connect and disconnect events relay consumes peak power. The detailed power consumption analysis is given below .

- Typically, a 12V coil latching relay is used in smart e-meters.
- The power requirement for such a relay range from 3W to 6W for 100ms in a single-phase smart e-meter, and from 4.5W to 9W for 100ms in a three-phase smart e-meter.
- The pulse duration requirement varies between 50ms and 100ms, depending on the relay manufacturer.

The specifications of IM901 relay from Ivy Metering are provided in Table 1-1.

Table 1-1. Specifications of IVY Metering IM901 Relay

Nominal coil operating voltage (V)	Minimum operating voltage (V)	Single Coil resistance (Ω)
6V	0.2V	24Ω
9V	6.3V	54Ω
12V	8.4V	96Ω
24V	16.8V	384Ω
48V	33.6V	1536Ω

In a typical smart e-meter, communication modem and latching relay are the critical power consuming components .A typical communication modem and latching relay consumes a peak power of 8W and 6W respectively. So, the total combines peak power requirement of these loads is 14W.

There are two ways to address this peak power requirement as discussed below:

1. **Option 1: Customized 15W SMPS Design**

   In this approach, the power supply is designed to directly meet the full peak power requirement. The customer must go with a 15W Switch mode power supply design with typically EE22-based transformer, two 68uF 400V bulk capacitor in series, bigger EMI filter resulting in larger PCB size and cost.

2. **Option 2: Standard 11W SMPS Design**

   In this approach, the power supply is sized for the average load, while peak relay energy is supported by a hold-up capacitor.

   Option 2 is preferred by manufacturers because of its size and cost effectiveness which will be discussed in the next section.

2 Conventional RC Circuit-Based Design

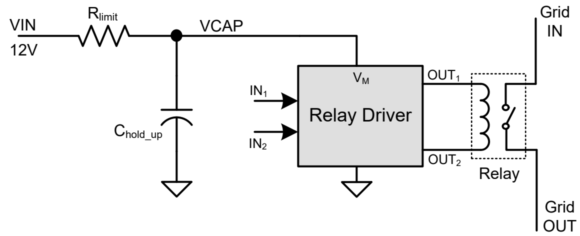

Figure 2-1. Block Diagram of Conventional RC Circuit-Based Design

In this conventional RC-based implementation, the latching relay peak power requirement is supplied by both hold-up capacitor ‘C_{hold_up}’ and power supply . ‘C_{hold_up}’ capacitor is connected to power supply with a series resistor ‘Rlimit’ (22Ω to approximately 100Ω), as shown in Figure 2-1, to limit the inrush current.

In a typical single phase smart e-meter:

- Nominal supply voltage = 12V
- Relay coil resistance = 96/2 = 48Ω
- Pulse duration = 50ms
- Relay operating voltage range = 12V to 8.4V
- Rlimit = 100Ω to limit inrush current to 120mA

During the latching period of 50ms, while the capacitor supplies the energy required to relay ,the voltage across the capacitor decreases . The voltage across relay (which is equal to voltage across capacitor) must be in the operating voltage range for the latching to be successful. The hold-up capacitor needs to support the peak energy consumed by relay, as well as maintain the relay voltage in the operating range for the latching to be successful. The minimum hold-up capacitor for successful latch is calculated using the Equation 1:

$$C_{hold\_up} = \frac{t_{pulse}}{\left(\frac{R_C \times Rlimit}{R_C + Rlimit}\right) \times \ln\left(\frac{V_{in} \times Rlimit}{[V_{min} \times Rlimit]) - [V_{in} - V_{min}]) \times R_C}\right)} \tag{1}$$

In the typical scenario described above, we need to install a capacitor of 3.3mF calculated using Equation 1 for the latching to be successful. A 3.3mF capacitor, typically 16mm in diameter and 25mm in height, is required to supply the relay's energy during latching, as the power supplied by the power supply is limited by the RLIM resistor in the RC configuration. This large capacitor occupies significant space in space-constrained smart meters. The test result of conventional RC circuit with 3.3mF of hold-up capacitor is shown in Figure 2-2.

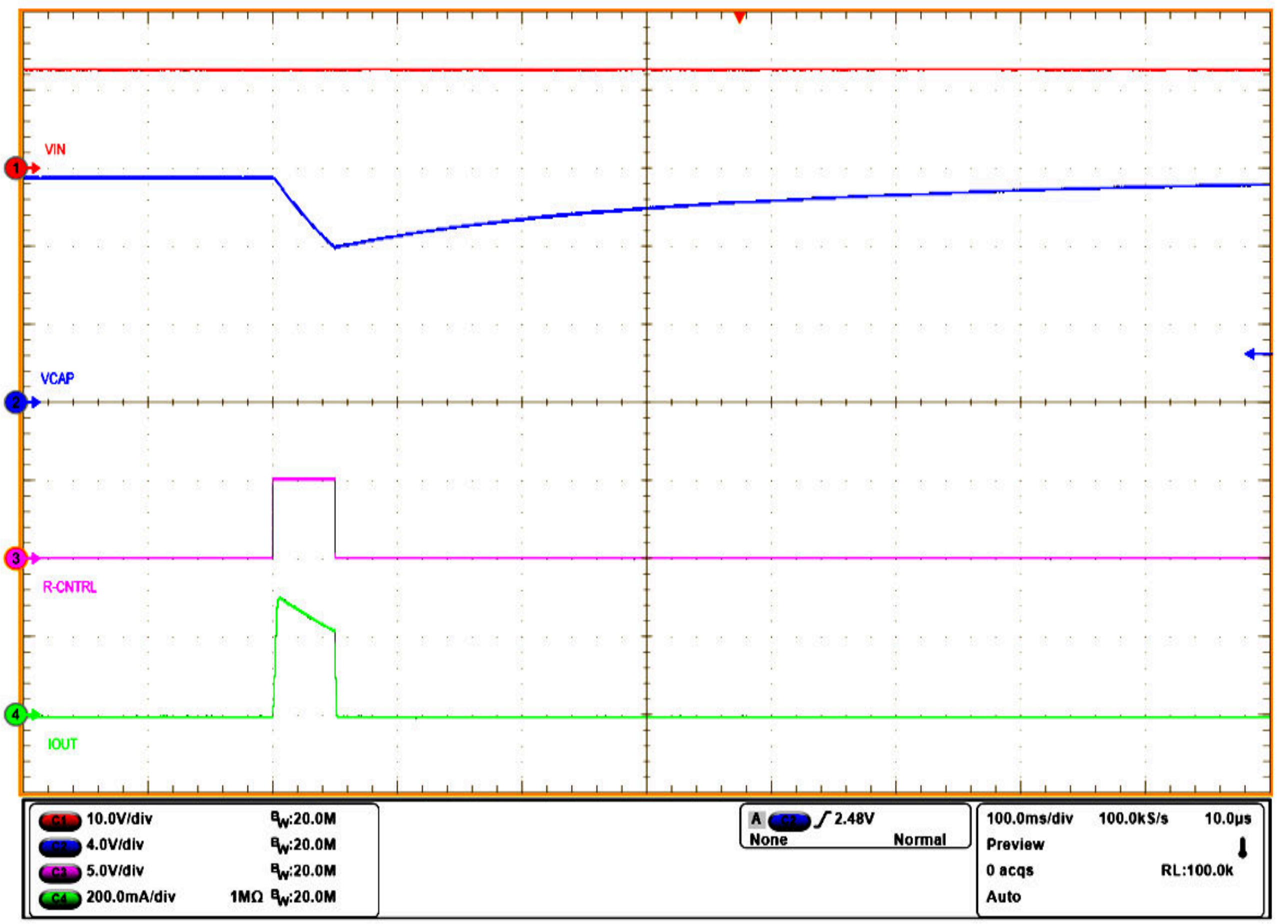

Figure 2-2. Test Result of Conventional RC Circuit With 3.3mF Of Hold-Up Capacitor

So, Customers require a design that:

- Reduces the capacitor size as it becomes a bottle neck in limited size of the energy meter while meeting the relay energy requirements
- Is capable of utilizing the available energy from the SMPS
- Provides overload and short-circuit protection on the 12V rail powering these relays
- Must bring e-meter fully functional within five seconds once mains power is applied. So, hold-up capacitor charging time must be <5sec

3 Proposed Design with eFuse

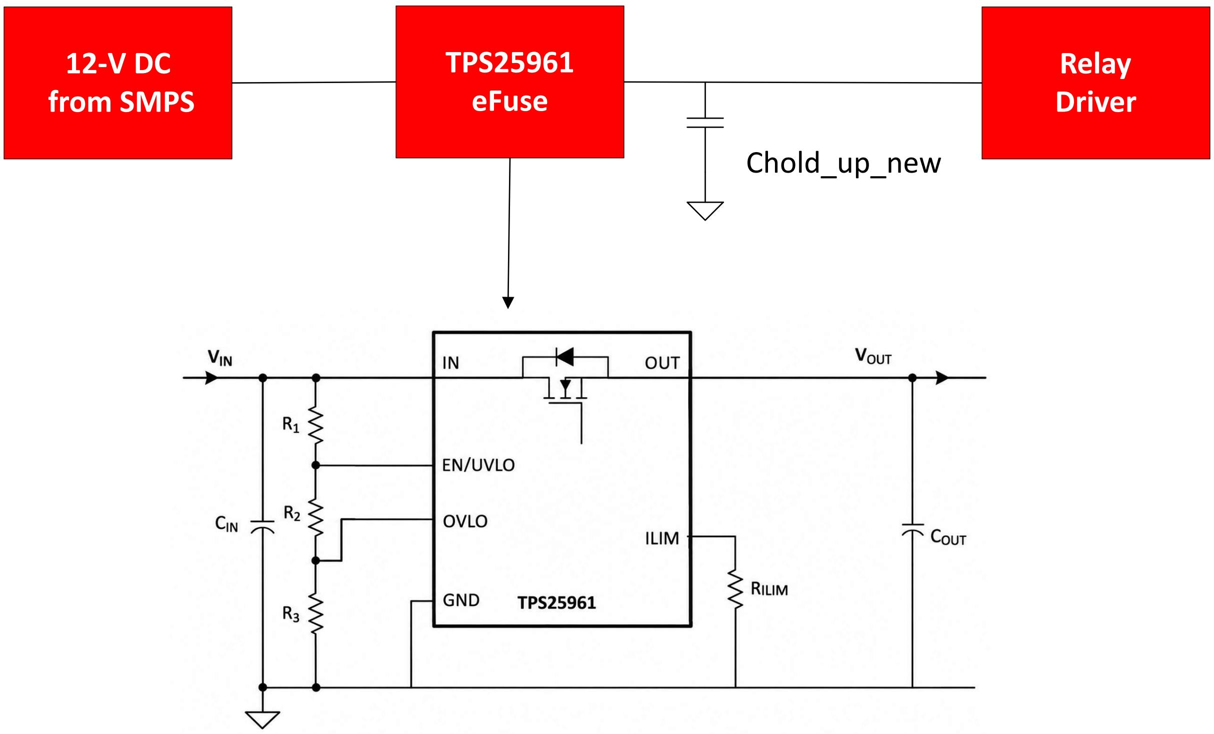

Figure 3-1. Block Diagram of EFuse-Based Design

As shown in Figure 3-1, the proposed design replaces the RLIM resistor with an eFuse. Unlike the conventional RC-based design where the supply current is limited by RLIM, the eFuse allows the current limit to be programmed through the ILIM pin. A higher current limit enables the power supply to deliver more energy during latching, thereby reducing the required hold-up capacitance.

The required hold-up capacitance can be calculated using Equation 2:

$$C_{hold\_up\_new} = \frac{t_{pulse}}{R_C \times \ln\left(\frac{V_{in} - ilim \times R_C}{V_{min} - ilim \times R_C}\right)} \quad (2)$$

In a typical single phase smart e-meter:

- Nominal supply voltage = 12V
- Relay coil resistance = 96/2 = 48Ω
- Pulse duration = 50ms
- Relay operating voltage range = 12V to 8.4V

A 1.5mF hold-up capacitor is required for successful latching under the above typical operating conditions, as calculated using Equation 2.

The minimum hold-up capacitance required at various eFuse current-limit settings was calculated, and the corresponding test results are shown in Figure 3-2 to Figure 3-4.

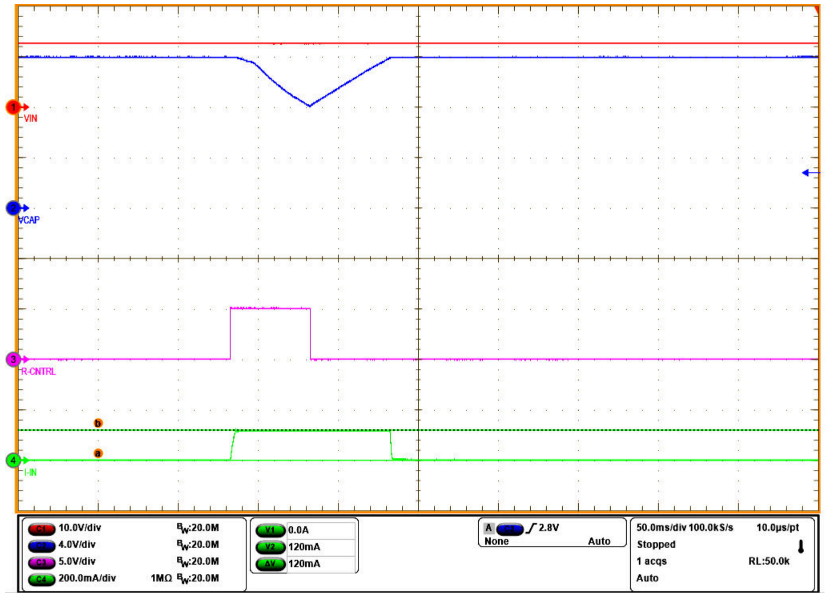

Figure 3-2. Test Result of Fixed ILIM = 120mA with 1.48mF of Hold-Up Capacitor

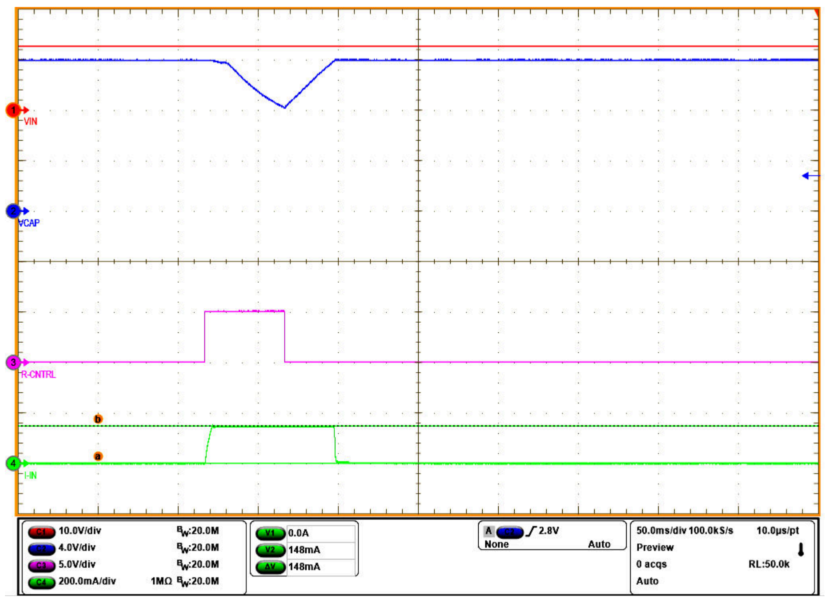

Figure 3-3. Test Result of Fixed ILIM = 150mA with 1.16mF of Hold-Up Capacitor

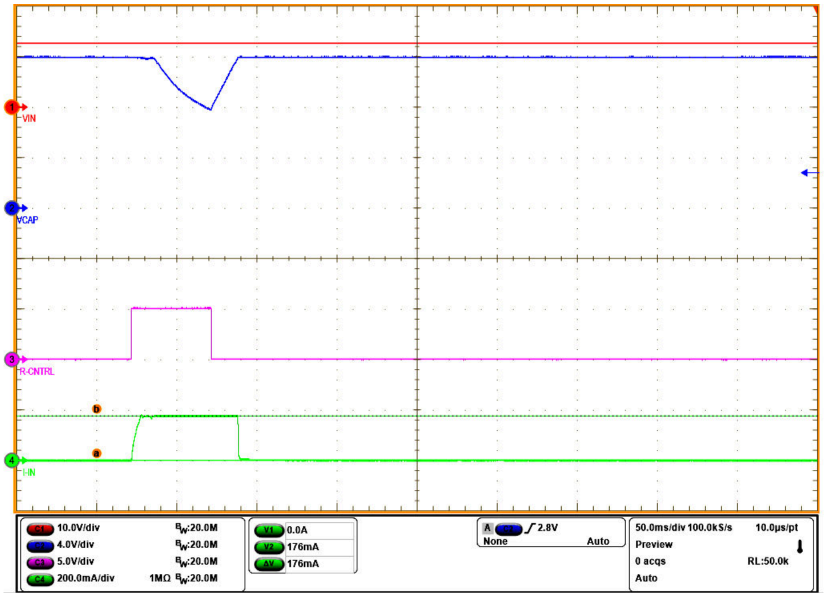

Figure 3-4. Test Result of Fixed ILIM = 180mA with 0.69mF of Hold-Up Capacitor

The test results in Figure 3-2 to Figure 3-4 show that increasing the current limit reduces the required hold-up capacitance. Therefore, the capacitor size is primarily determined by the current limit during the latching phase.

A dynamic current limit method can further optimize both capacitor size and power consumption by configuring a higher current limit during latching and a lower limit during steady-state operation. This allows the SMPS to provide maximum available energy during latching while reducing the steady current during steady state. The dynamic current implementation is described below and shown in Figure 3-5.

Implementation of dynamic current limit:

- **Current-limit configuration**: The ILIM pin is connected to RILIM_startup and RILIM_pulse, with an N-channel MOSFET used to switch between the two current-limit settings.
- **During latching**: Upon receiving a relay-latching command, the microcontroller turns ON the N-channel MOSFET, enabling RILIM_pulse and setting the eFuse to the higher current limit.
- **After latching**: The microcontroller turns OFF the MOSFET, disabling RILIM_pulse and returning the eFuse to the lower current limit set by RILIM_startup.

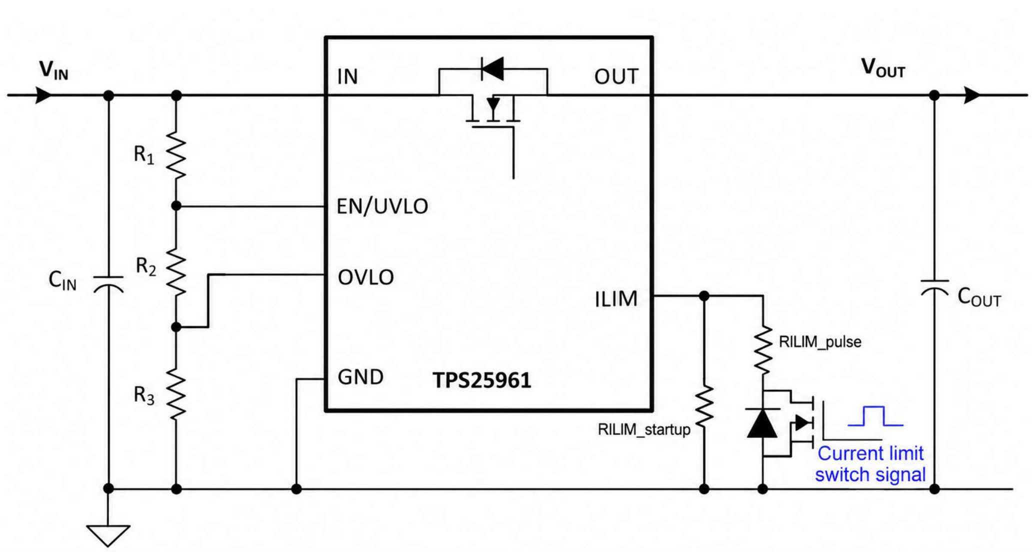

Figure 3-5. Design Using Dynamic Current Limit Feature Circuit of eFuse

The dynamic current-limiting tests were performed with the lower current limit fixed at 120mA and different higher current-limit values. A 5V DC gate signal was applied to the N-channel MOSFET for 50ms to enable the higher current limit. After 50ms, the current limit returned to 120mA in each test. The corresponding test results are shown in Figure 3-6 and Figure 3-7.

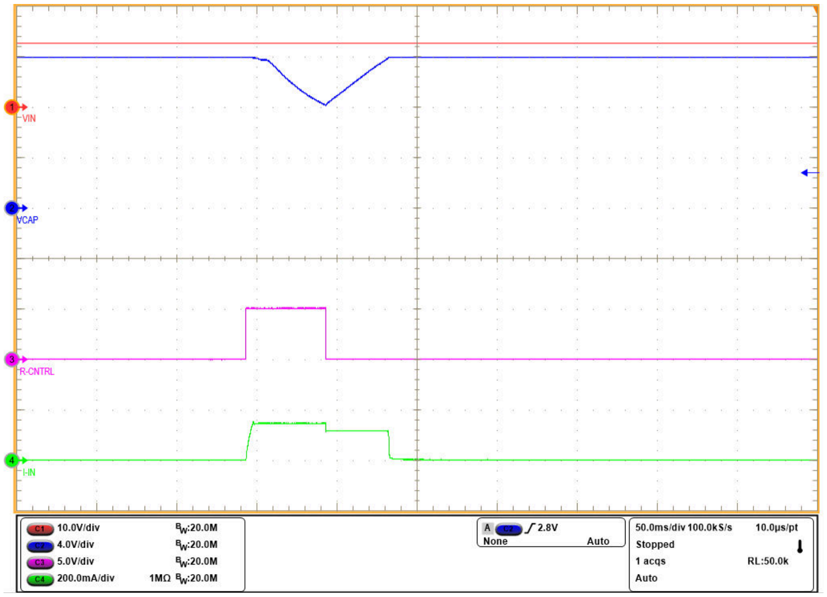

Figure 3-6. Test Result of Dynamic ILIM = 150mA with 1.16mF of Hold-Up Capacitor

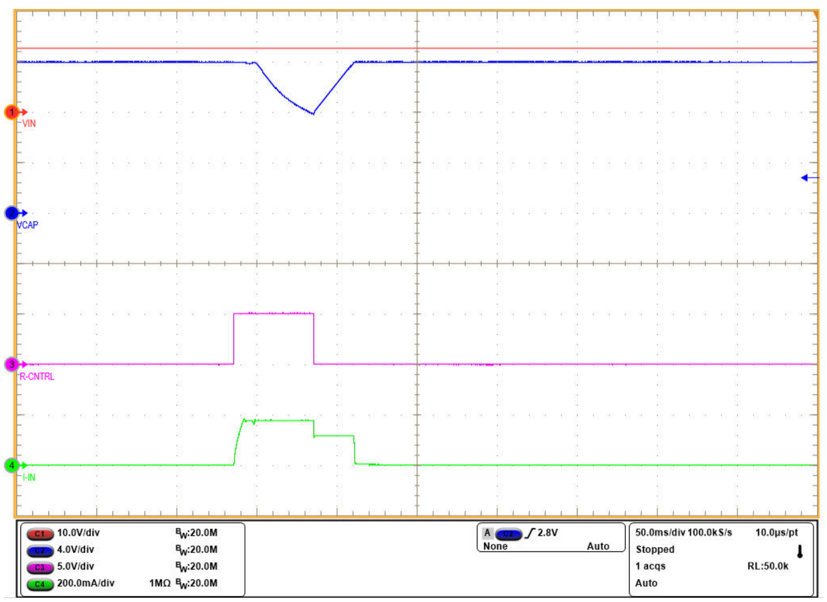

Figure 3-7. Test Result of Dynamic ILIM = 180mA with 0.69mF of Hold-Up Capacitor

Consider the implementation circuit corresponding to the test results shown in Figure 3-7. The inrush current limit is set to 120mA, while the latching-phase current limit is set to 180mA. With dynamic current limiting, the required hold-up capacitor is 0.69mF, compared with 3.3mF used in the conventional non-eFuse design.

4 Comparison Summary and Conclusion

Table 4-1. Capacitor Size Comparison: Conventional RC vs eFuse-Based Design

	Conventional RC-based Design		eFuse-Based Design	
Current Limit in Latching Phase (mA)	**Capacitor Installed (uF)**	**Capacitor Size (mm^2)**	**Capacitor Installed (uF)**	**Capacitor Size (mm^2)**
120	3300	400	1500	225
150	2200	313	1000	200
180	2200	313	470	125

Table 4-1 compares the capacitor requirements of the conventional RC-based and eFuse-based designs for different latching current limits. The eFuse-based design has significantly reduced the required capacitor size and the reduction in capacitor size can offset the additional eFuse cost, reducing the overall design cost.

The eFuse supplements the hold-up capacitor by utilizing the available supply power during the pulsed load, reducing the required capacitor size for a given backup time. With dynamic current limiting, the eFuse operates at a lower current limit during latching and a higher current limit during normal operation. This allows greater utilization of the available supply power and further reduces the hold-up capacitor requirement. The TPS25961 also provides overvoltage protection, overload and short-circuit protection, improving overall system protection.

5 References

- Texas Instruments, TPS25961 2.7-V–19-V, 106-mΩ, eFuse With Adjustable Current Limit and Short-Circuit Protection, datasheet
- Texas Instruments, TPS25961 Design Calculator